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The impact of nature-based interventions on public health: a review using pathways, mechanisms and behaviour change techniques from environmental social science and health behaviour change

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Abstract: The aim of this narrative review is to explore whether nature-based interventions improved individual public health outcomes and health behaviours, using a conceptual framework that included pathways and pathway domains, mechanisms, and behaviour change techniques derived from environmental social science theory and health behaviour change models. A two-stage scoping methodology was used to identified studies published between 2000 and 2021. Peer reviewed, English-language reports of nature-based interventions with adults ($N = 9$) were included if the study met the definition of a health–behaviour change intervention and reported at least one measured physical/mental health outcome. Interventions focused on the restoring or building capacities pathway domains as part of the nature contact/experience pathway; varied health behaviour change mechanisms and techniques were present but environmental social-science-derived mechanisms to influence health outcomes were used less. Practical recommendations for future interventions include explicit statement of the targeted level of causation, as well as utilisation of both environmental social science and health behaviour change theories and varied public health outcomes to allow simultaneously testing of theoretical predictions.

Keywords: Urban greenspace, intervention, pathways, mechanisms, public health, behaviour change, wellbeing.

Notes on the authors: see end of article.

Urban nature impacts public and climate health

When effectively designed, urban nature has significant potential to contribute to public and climate health. The World Health Organization (WHO 2018a 2020) recognises the interplay between urban environments and varied public health outcomes, stating 'health and wellbeing is essential to achieving sustainable development' (WHO 2018b: 8). A key component of healthy, sustainable urban environments is that they support individuals in leading a healthy lifestyle (WHO 2020). Therefore, it is important to understand the complex interrelationships between people, their health and wellbeing, and nature.

Evidence supports a positive relationship between nature generally and health outcomes, including improved life expectancy (Gidlow *et al.* 2016, Kondo *et al.* 2018, van den Berg *et al.* 2015, van den Bosch & Ode Sang 2017, WHO 2016), blood lipids and blood pressure (Twohig-Bennett & Jones 2018), and immune functioning (WHO 2016), as well as lower physiological stress biomarkers (Hunter *et al.* 2019, Keniger *et al.* 2013, Kondo *et al.* 2018, Thompson *et al.* 2012) and weight (WHO 2016). Mental health and wellbeing outcomes associated with nature include better life satisfaction, mood, and cognition (Houlden *et al.* 2018, Kondo *et al.* 2018, McMahan & Estes 2015, Rogerson *et al.* 2016). Urban nature also provides societal benefits, including increased social cohesion and social interaction (Jennings & Bamkole 2019) and has the clear potential to improve air quality and biodiversity (Aronson *et al.* 2017). Additionally, contact with nature may promote pro-environmental behaviours beneficial to climate health (Halpenny 2010, Scannell & Gifford 2010, WHO 2016).

Due to the evidence supporting individual, societal, and climate-related benefits, calls have been made to investigate how nature-based interventions (NBIs) can improve public health and, specifically, to quantify their impact on a range of health outcomes (PHE 2014, Shanahan *et al.* 2015), defined as 'the impact that a test, treatment, policy, programme or other intervention has on a person, group or population' (NICE 2019). NBIs, whether occurring in urban nature or more wild/less managed nature, are defined as 'programmes, activities, or strategies that aim to engage people in nature-based experiences with the specific goal of achieving health and wellbeing' (Shanahan *et al.* 2019: 142). The challenge lies in designing NBIs that are able to: 1) improve public health outcomes and change individual health behaviours, 2) explain the pathways underlying any identified nature–health linkages, and 3) use theory to test the mechanisms through which pathways function. Our aim was to explore whether these three challenges were being met in published accounts of NBIs.

To achieve this aim, we present a narrative synthesis review of urban NBIs grounded in environmental social science and health behaviour change. We believe NBI design will be enhanced if health behaviour change is systematically recognised

in causal frameworks linking nature to health. This is a unique contribution of the review. First, we explore the ways in which terms of causation, such as pathways and mechanisms, are being used to link nature and health. From this, a conceptual framework consisting of pathways, mechanisms, and behaviour change techniques is presented in the next section. This conceptual framework is used to map NBI studies and generate a narrative synthesis of urban NBI impacts on health and wellbeing. In the final section, future directions and practical recommendations for NBI design based on the review findings are presented.

A conceptual framework of the pathways and mechanisms linking urban nature and health

Several authors have recently proposed frameworks to identify and organise the causal pathways and mechanisms that produce nature's effects on a range of health outcomes (for example, Bratman *et al.* 2019, Hartig *et al.* 2014, Marselle *et al.* 2021, Shanahan *et al.* 2015). In this section, these frameworks are further developed to address two perceived limitations and provide some clarification for the wider NBI discourse.

One limitation of these frameworks and the wider NBI evidence base is a lack of consensus regarding definitions of pathways and mechanisms. Many studies do not clearly define either term (Bratman *et al.* 2019, Hartig *et al.* 2014, Kruize *et al.* 2019, Markevych *et al.* 2017, Masterton *et al.* 2002, Prins *et al.* 2016, Shanahan *et al.* 2015, Silva *et al.* 2018). Others use these terms interchangeably (Husk *et al.* 2016, Kuo 2015, Lovell *et al.* 2016, Triguero-Mas *et al.* 2015). Although terminology use has not always been clear, several key similarities exist. First, there is a recognition of hierarchical structures in the causal relationship (Hedström & Ylikoski 2010). Pathways typically refer to broad, higher-order constructs (Frank 2019, Hartig 2014, Jennings & Bamkole 2019, Kruize *et al.* 2019, Kuo 2015, Lachowyz & Jones 2013, McNeill *et al.* 2006, Prins *et al.* 2016, Shanahan *et al.* 2015, Silva *et al.* 2018), and mechanism is used as the 'action' word to explain how the pathway evokes an effect (Frank *et al.* 2019, Hartig *et al.* 2014, Jennings & Bamkole 2019, Kabisch *et al.* 2017) or the mediator through which the outcome occurs (Frumpkin *et al.* 2017, Lachowyz & Jones 2013, Prins *et al.* 2016). Another limitation is a lack of clarity regarding which term has priority in the causal chain between nature and health. In one case, pathways were considered part of a mechanism (Frumpkin *et al.* 2017) but, more commonly, mechanisms were referred to as part of a pathway as the mediating influence *through which* the pathway affected the outcome of interest (Frank *et al.* 2019, Hartig *et al.* 2014, Kruize *et al.* 2019, Prins *et al.* 2016).

To some extent, these limitations mirror wider scientific debate around the 'black box' of causality (Astbury & Leeuw 2010, Gerring 2007, Hedström & Ylikosky 2010, Imai *et al.* 2011, Ross 2018, Shapiro 2017). The 'black box' typically refers to a general causal relationship between two variables (X, Y) and *whether* X impacts Y (Astbury & Leeuw 2010, Gerring 2007, Imai *et al.* 2011, Shapiro 2017). However, researchers also need to understand *how* X influences Y to fully understand this causal relationship. In the wider debate, *how* is referred to as exploring the 'white box' (or boxes) in causal relationships (Baron & Kenny 1986, Gerring 2007, Imai *et al.* 2011). In other words, it is important to understand both *whether* and *how* X creates any change in Y (Tate *et al.* 2016).

In an attempt to provide some clarification about the causal relationship between variables in NBI research, we propose that pathway (X) aligns with the 'black box' and mechanism refers to one or more 'white boxes' within the black box.[1] This distinction is consistent with the *Oxford English Dictionary* definitions of pathway and mechanism (*OED* 2021), as well as some of the biological science discourse where pathways refer to '*whether*' or '*that*' X causes a change in Y, while mechanisms explain '*how*' (Ross 2018: 15). We suggest this distinction is also consistent with the general spirit (if not execution) in the existing literature exploring the links between nature and health.

Based on this distinction and drawing on earlier work, we propose a conceptual framework of pathways and the mechanisms that underly them (see Table 1). This framework consists of two levels of pathways: superordinate pathways and subordinate pathway domains.[2] At the highest level, the nature–health link results from two superordinate pathways: *nature exposure* and *nature contact/experience* (Bratman *et al.* 2019, Hartig *et al.* 2014, Marselle *et al.* 2021). Nature exposure refers primarily to direct ecological benefits of nature, including the amount, proximity, and quality of nearby greenspace (Hartig *et al.* 2014, Lachowyz & Jones 2013, Shanahan *et al.* 2015). Nature exposure does not require an individual to be present in nature to receive benefits (for example, Shanahan *et al.* 2015). For example, local area greenspace operates in a zone around the home even though residents may not necessarily 'partake' in this greenspace (Marselles *et al.* 2021). Exposure is differentiated from nature contact or experience, because people's contact with and experience of nature vary

[1] We are not advising that NBIs should be inherently biologically focused and/or excessively *mechanistic* in their design. Instead, we borrowed this distinction from Ross (2018) to contribute to discussions amongst nature–health researchers, particularly to facilitate determining how NBIs work (or do not) and for whom.

[2] Superordinate pathways and their subordinate domains can (and likely do) operate simultaneously in urban greenspace (UGS) NBIs. For example, nature experience and restoring capacities can operate simultaneously with nature exposure and biodiversity during that experience.

Table 1. Proposed pathways, pathway domains, mechanisms, and public health outcomes of nature-based interventions.

Pathway[a]	*Pathway Domains*[b]	*Mechanisms*	*Public Health Outcomes*
	Reducing Harm[b]		Physical Health Indicators
		Air pollution mitigation	Adrenaline
	Air quality	Heat and noise abatement	Aerobic fitness
	Biodiversity	Beneficial microbiota	Blood pressure
Nature Exposure	Ecological quality	Phytoncides	Body mass index
		Sunlight	Cholesterol
			Cortisol (salivary, serum)
	Restoring Capacities[b]		Dopamine
			Heart rate/heart rate variability
	Restoration of depleted psychological capacity	Cognitive restoration[1]	Immune function
		Positive emotion[2]	Mortality
			Recommended MVPA[e] met
			Respiratory symptoms
			Vitamin D absorbtion
	Building Capacities[b]		Weight/weight loss
	Physical activity and other health behaviours	Behavioural regulation[3] (C)	Wellbeing Indicators
		Beliefs about capabilities[3] (M)	
		Beliefs about consequences[3] (M)	
		Environmental context/ resources[3] (O)	Affect/mood
Nature Contact/ Experience		Goals[3] (M)	Anxiety
		Intentions[3] (M)	Burnout
		Knowledge[3] (C)	Depression
	Social contact/ interaction	Memory, attention, decision making[3] (C)	Fatigue
		Skills[3] (C)	Health-related quality of life
		Social influence[3] (O)	Restoration
			Rumination
			Psychosomatic complaints
			Self-reported health
	Causing Harm[b]		Self-reported stress
			Social cohesion
	Air quality	Allergens	Social isolation
	Ecological quality	Harmful microbiota	
		Zoonotic or infectious disease	

Table 1. *Cont*.

[a] The order of pathways in the table is not meant to imply that one is of greater importance that the other. Pathways are the X in the link between nature and health and wellbeing.

[b]Pathway domains are considered part of a hierarchical structure, where pathways are superordinate and domains are several possible ways in which the pathway (X) can be operationlised. Pathway domains may link to one or both pathways, so do not necessarily follow on from the first column.

[c]However, the proposed mechanisms are linked to specific pathway domains based on prior evidence and/or theoretically derived processes that should produce an effect.

[d]Public health indicators may also be affected by one or more pathway, pathway domain, or mechanism. Therefore they do not directly follow on from the previous column.

[e]MVPA = moderate-to-vigorous physical activity. Adults are recommended to engage in a minimum of 150 minutes/week (WHO 2018b).

[1]Attention restoration theory (Kaplan 1995, Kaplan & Kaplan 1989).

[2]Stress reduction theory (Ulrich *et al.* 1991).

[3]Theoretical domains framework (Cane *et al.* 2012) which represents constructs from 33 theories of behaviour.

C = capability, O = opportunity, M = motivation (Cane *et al.* 2012, Michie *et al.*. 2011).

Sources: This table is based on conceptual models by Marselle *et al.* (2021), Hartig *et al.* (2014), Shanahan *et al.* (2015) and, to a lesser extent, Bratman *et al.* (2019) and was guided by a framework of causal explanation in the biological sciences proposed by Ross (2018).

within the same greenspace (Bratman *et al.* 2019). Nature experience has been referred to as the 'subjective experience of nature' (Hartig *et al.* 2014: 209) and includes both the way in which people interact with nature and the 'dose' or duration of this interaction (Bratman *et al.* 2019).

In several nature–health frameworks, nature exposure and nature contact/experience are linked, directly or indirectly, to additional factors to provide a more nuanced explanation '*whether*' nature produces changes to health and wellbeing (for example, Marselles *et al.* 2021). These pathway-related factors include air/ecological quality, biodiversity, physical activity, psychological processes, social interaction (Bratman *et al.* 2019, Hartig *et al.* 2014, Shanahan *et al.* 2015, Zhou *et al.* 2020), and immune functioning (Kruize *et al.*. 2019, Kuo 2015, Silva *et al.* 2018). These factors provide an additional level of detail within the 'black boxes' (pathways) of nature exposure and contact/experience. Unfortunately, these factors are often also referred to as pathways. Instead, the two superordinate pathways should be distinguished from these factors to avoid confusion. In our conceptual framework, we refer to the latter as four subordinate pathway domains proposed by others (Dzambov *et al.* 2020, Markevych *et al.* 2017, Marselle *et al.* 2021): *reducing harm* (air quality), *restoring capacities* (psychological processes), *building capacities* (physical activity, social interaction), and *causing harm* (exposure to allergens, disease). We suggest that pathway domain is an appropriate term because it is consistent with the definition of a domain

as 'a set of possible values of the independent variable or variables of a function' (*OED* 2021).

Mechanisms (*how*) operate within pathway domains; and multiple mechanisms can also be in action simultaneously both within and across pathway domains. In this review, direct and indirect causal pathways via possible mechanisms will not be addressed, as other authors have proposed structurally different models for this (Hartig *et al.* 2014, Lachowyz & Jones 2013, Marselle *et al.* 2021). Instead, our aim was to unpack the 'black boxes' of pathways and their domains from the 'white boxes' within, representing the possible mechanisms of each (see Table 1). This also allows theoretical explanations for different mechanisms to be incorporated into the conceptual framework, so competing or complementary theoretical predictions may be tested.

In the review presented here, the focus was on the two *capacities* pathway domains. *Restoring capacities* refers to the improvement or restoration of depleted psychologic--al processes adversely impacted from daily life and urban living. This pathway domain is linked to the nature contact/experience pathway and has foundations in two theoretical positions from environmental psychology and environmental social science. Stress reduction theory (SRT: Ulrich, 1983, Ulrich *et al.* 1991) proposes that the mechanism by which nature experience restores depleted psychological capacities is through unconscious positive emotions, evoked by nature, which generate a reduction in physiological stress responses. In attention restoration theory (ART: Kaplan, 1995, Kaplan & Kaplan, 1989), the recovery of depleted cognitive resources is the central mechanism by which nature exposure restores capacities to produce a myriad of health and wellbeing benefits.

The *building capacity* pathway domain is also linked with the nature contact/experience and focused on health-related behaviours. Physical activity is one of the most widely researched health behaviours in the context of urban and nature-based interventions (Wilkie & Davinson 2021, Wilkie *et al.* 2018). Building capacity may also encompass other health-related behaviours, such as active transportation for work/daily tasks (Lachowyz & Jones 2013) and social contact (Jennings & Bamkole 2019). The mechanisms by which these capacities are built can be viewed through health behaviour change theory (Cane *et al.* 2012), which generally aims to understand health behaviour in order to design interventions that can produce desired positive behavioural outcomes (Cane *et al.* 2012, Davis, *et al.* 2015). Our review includes mechanisms identified through the theoretical domains framework (TDF: Cane *et al.* 2012) and capability–opportunity–motivation (COM-B) system of behaviour (COM-B: Michie *et al.* 2011, 2014). Examples include individual beliefs about their capabilities and confidence to engage in health behaviours, setting goals to complete behaviours, and regulating behaviours through self-monitoring.

This approach provides a strong foundation for NBI design because there are over ninety different behaviour change techniques targeting a variety of mechanisms to elicit health behaviour change (Carey *et al.* 2019, Michie *et al.* 2013) and improve the desired health and wellbeing outcomes.

The addition of health behaviour change as part of the *building capacities* pathway domain was a unique aspect of our conceptual framework. NBIs aim to improve health, but only a few studies have explored their impact through this lens (for example, Pretty & Barton 2021). The inclusion of a health behaviour change as a pathway domain also addresses a limitation of existing frameworks, which speculate on theoretical mechanisms through which pathways/domains might operate. However, they do not consider how interventions produce the desired behaviours needed to ensure NBIs are successful (Pretty & Barton 2021). In short, there is an important aspect of NBIs that has yet to be investigated, based on many existing frameworks.[3]

Behaviour change techniques (BCTs) are the active components of a behaviour change interventions. They have been used to change health behaviours, such as promoting physical activity (Howlett *et al.* 2015) and improving diet (Cradock *et al.* 2017) and should be clearly defined, observable, and replicable (Human Behaviour Change Project 2021, Michie *et al.* 2013). BCTs are important because they are the essential components of health–behaviour interventions, defined as a 'coordinated set of activities designed to change specified behaviour patterns' (Michie *et al.* 2011: 1). One critique of existing NBIs is that many lack the necessary detail to assess whether the intervention was successful (Prestwich *et al.* 2015, Roberts *et al.* 2016). In the current review, we explored whether NBIs were utilising BCTs and, if so, whether NBI activities corresponded with intervention techniques commonly used to elicit behaviour change (Human Behaviour Change Project 2021, Michie *et al.* 2013).

A narrative synthesis of pathways, mechanisms, behaviour change techniques, and health outcomes in urban greenspace NBIs

The study selection process followed general guidance for scoping reviews (Arksey & O'Malley 2005, Colquhoun *et al.* 2014). The urban greenspace (UGS) NBIs included in this review were selected using the following inclusion criteria: 1) they had at least one measured physical or mental health public health outcome (PHE 2016, WHO 2018b), 2) they were conducted with adults, 3) the full text is available in English, 3) they are peer reviewed, 4) they were published between January 2000 and September 2021, and 5) they used the term 'intervention' in a manner consistent with health

[3] An exception was Frank *et al.* (2019), who included behaviour in their causal diagram.

behaviour change (Michie *et al.* 2011). Studies with children, mixed methods, and qualitative studies were excluded.

Nine studies were identified from Web of Science, PubMed, and Science Direct databases during the census period. Five studies (1–4, 9 in the Appendix) were identified in a scoping review of 52 studies focused on the terms, methods, and public health indicators used in NBIs (Wilkie & Davinson 2021). Although not a requirement of the initial scoping review, these five studies used 'intervention' in the required way. Building on that review, a similar search procedure was implemented in Science Direct and Web of Science (September 2019–January 2021). This involved using combinations of search terms: for example, greenspace AND intervention AND wellbeing. Identified abstracts (N = 33) were reviewed against inclusion/exclusion criteria from the prior study, as well as an additional criterion to meet the health behaviour change intervention definition. After abstract review, nine were reviewed in full-text; five were excluded because they did not use intervention as required. This resulted in four additional studies for the narrative synthesis that follows, along with the five from the prior review.

There was some challenge in developing the narrative synthesis. It was often necessary to deduce the intended pathways, pathway domains, mechanisms, and behaviour change techniques from study descriptions, despite meeting the definition specified for this review. This challenge was compounded by three studies that did not provide a clear theoretical position guiding the NBI. Therefore, in many ways, the narrative findings to follow are also a case study of whether and (if so) how the mapping approach based on our conceptual framework could be used to assess published accounts of NBIs. The Appendix provides a summary of pathways/pathway domains, mechanisms, behaviour change techniques, and public health outcomes for each included study, as well as descriptions of study samples, settings, and methods.

Results

Although the census period began in 2000, all included studies were published between 2016 and 2020. Four studies were with samples at risk or diagnosed with physical or mental health conditions (Beute & de Kort 2018, Dolling *et al.* 2017, Maund, *et al.* 2019, Plotnikoff *et al.* 2017). Most studies implemented between-subject or randomised control trial designs (Bang *et al.* 2017, Caloguiri *et al.* 2016, Dolling *et al.* 2017, Muller-Riemenschneider *et al.* 2020, Payne *et al.* 2020, Plotnikoff *et al.* 2017). The remainder were within-subject designs. NBI settings ranged from grass yards and wetlands, from parks, to managed forests and university settings near mountains; however, one study asked participants to engage with a nature setting of their choosing

(Payne *et al.* 2020). In another, participants were presented with varied images of natural scenes (Beute & de Kort 2018).

First, we explored any positive impacts of the NBIs on health, wellbeing, and individual health behaviours. Evidence-supported NBIs had a positive influence on physiological health indicators, including aerobic fitness (Plotnikoff *et al.* 2017), body composition and fitness (Bang *et al.* 2017, Plotnikoff *et al.* 2017), heart rate (Bang *et al.* 2017, Beute & de Kort 2018), blood pressure (Caloguiri, *et al.* 2016, Plotnikoff *et al.* 2017), and cortisol (Caloguiri, *et al.* 2016). Three studies reported improved health promoting behaviour or physical activity (Bang *et al.* 2017, Muller-Riemenschneider *et al.* 2020, Plotnikoff *et al.* 2017). Collectively, there was also support for improvements to perceived general health (Dolling *et al.* 2017), mood (Beute & de Kort 2018, Caloguiri, *et al.* 2016, Dolling *et al.* 2017, Maund *et al.* 2019, McEwan *et al.* 2019), perceived stress (Dolling *et al.* 2017, Maund *et al.* 2019, Payne *et al.* 2020), quality of life (McEwan *et al.* 2019) and reduced rumination (Beute & de Kort 2018), burnout, and fatigue (Dolling *et al.* 2017).

Next, the pathways underlying any identified nature–health linkages were mapped using our conceptual framework. All were focused on the *nature contact and experience* pathway. Three studies (Bang *et al.* 2017, Müeller-Riemenschneider *et al.* 2020, Plotnikoff *et al.* 2017) focused only on the *building capacities* pathway domain, while one targeted this domain and *restoring capacities* (Calogiuri *et al.* 2016). The five remaining studies focused only on the *restoring capacities* pathway domain. No studies utilised the *nature exposure* pathway or the *reducing/causing harm* pathway domains.

Another challenge was to determine whether theories and the associated mechanisms through which these pathways functioned were being reported and/or tested. Encouragingly, a range of mechanisms and behaviour change techniques aligned with health behaviour change theories were present in all the NBIs we reviewed. Across the included NBIs, mechanisms associated with *psychological* and *physical capabilities* were the most prevalent aspects of the COM-B (Michie *et al.* 2011), followed by *reflective* and *automatic motivation*, and provision of *physical* and/or *social opportunities*. Commonly used health behaviour change mechanisms present in the NBIs included knowledge, environmental contexts and resources, and memory, attention, and decision processes (TDF: Cane *et al.* 2012). In terms of BCTs implemented, self-monitoring of behaviour, consequences of behaviour, or emotional consequences of behaviour were widely used, as well as prompts or cues, biofeedback, and instruction on how to complete the behaviour (BCTTv1: Human Behaviour Change Project 2021, Michie *et al.* 2013).

Links between environmental social science theories and their possible mechanisms were less clear. Four studies referred to either or both ART (Kaplan 1995, Kaplan & Kaplan 1989) and SRT (Ulrich 1983, Ulrich *et al.* 1991) as the theoretical basis.

From study descriptions, the mechanism of positive emotion (SRT) was present in six studies (Beute & de Kort 2018, Caligiuri *et al.* 2016, Dolling *et al.* 2017, Maund *et al.* 2019, McEwan *et al.* 2019, Payne *et al* 2020). Of these, five measured perceived stress or stress biomarkers. It was not clear from task descriptions whether they also targeted positive emotion as a technique to reduce stress, also consistent with SRT. An exception was a study by McEwan and colleagues (2019) prompting participants to note one good thing about their allocated environment. The phrase 'good' suggests the intention was to invoke the positive emotion mechanism; however, no stress-related outcome was measured. Conversely, noticing one good thing could also have been a cognitive restoration mechanism (ART). In ART, depleted cognitive resources recover by focusing one's attention to nature's softly fascinating (that is, good) characteristics to allow directed attention to restored (Kaplan 1995, Kaplan & Kaplan 1989). The study appeared more closely aligned to ART than SRT based on measured outcomes, including mood, nature engagement, and nature-related identity. Three other studies likely utilised the cognitive restoration mechanism, based on the inclusion of ART in the study rationale or the general intervention description (Caloguiri *et al.* 2016, Dolling *et al.* 2017, Payne *et al.* 2020). Yet, there was no apparent targeting of cognitive restoration techniques in the study designs. Without stated links between theoretically derived mechanisms and clearly described NBI techniques, testing the pathway between nature and health-related outcomes is limited; nor can the mechanisms be assessed for their relative contributions to any impact nature may have on public health.

However, two interventions were considered examples of best practice both in NBI design and reporting due to the clear use of health behaviour change theory. The first was a group forest walking NBI targeting the *building capacity* pathway domain through physical activity and using the information–motivation–behavioral skills model (IMB: Fisher *et al.* 1994, as cited in Bang *et al.* 2017). It was clear which IMB mechanisms were targeted. As a result, TDF mechanisms (Cane *et al.* 2012) and BCTs from the BCTTv1 (Michie *et al.* 2013) could be mapped. Similarly, a randomised control trial NBI (Plotnikoff *et al.* 2017) used two health behaviour theories and the Health Action Process Approach behaviour change model (Schwarzer & Luszcynksa 2015, as cited in Plotnikoff *et al.* 2017) which allowed straightforward mapping to BCTs. This study also had a published protocol providing more extensive intervention design details and was considered another example of best practice (Jansson *et al.* 2019).

Finally, there were some additional findings of relevance to wider climate health. In one NBI, park use improved (Müller-Riemenshneider *et al.* 2020). Park use is considered a way to improve an individual's attitudes towards nature. This was also evidenced in another NBI, where nature relatedness increased (McEwan *et al.* 2019). Nature relatedness and connectedness are constructs referring to an individual's desire

to be in nature and feelings of attachment/belonging to nature (Tam 2013). These concepts are linked with higher levels of pro-environmental behaviours (Mackay & Schmitt 2019, Martin *et al.* 2020, Whitburn *et al.* 2018).

Future directions and recommendations for urban nature-based interventions

The aim of this narrative review was to explore whether nature-based interventions improved individual public health outcomes and health behaviours. Prior work influential to our endeavour bridged environmental social science, environmental science, and public health (for example, Bratman *et al.* 2019, Hartig *et al.* 2014, Marselle *et al.* 2021, Shanahan *et al.* 2015); but the concepts and frameworks used to explore causal pathways between nature and health first needed to be disentangled. In this regard, one unintended (and hopefully beneficial) contribution of this review was the use of literature on causal pathways in the biological and social sciences to better understand the link between nature and health. Guided by Ross (2018), we proposed clear distinctions between pathways as the higher-order, superordinate causal variables (X), their subordinate pathway domains linked to theory, and the mechanisms by which both operate to influence a specific outcome (Y).

A conceptual framework consisting of two pathways linking nature and public health was proposed: *nature exposure* and *nature contact/experience*. Consistent with Marselle and colleagues (2021), we suggested these pathways had four pathway domains: *reducing harm, causing harm*, *restoring capacities*, and *building capacities*. As such, our framework was a reconceptualisation of prior frameworks that used the terms pathways, domains, and mechanisms in different ways or, in some cases, interchangeably.

Although numerous NBIs exist, very few explicitly drew on health behaviour research. We synthesised the findings of nine NBIs targeting measured public health outcomes. Specifically, we found these NBIs focused only on the *nature contact/exposure* pathway and the *building* and/or *restoring capacities* pathway domains. Pathway domains were aligned to mechanisms derived from environmental social science and health behaviour theories and behaviour change techniques widely used in health behaviour change interventions. In that regard, as a case study of the application of the proposed conceptual framework for NBI evaluation, the narrative synthesis was broadly successful.

Physiological health benefits were almost exclusively through the *building capacities* pathway domain. Positive subjective wellbeing outcomes were mostly a consequence of the *restoring capacities* pathway domain. This division between pathway domains of public health outcomes was not wholly unexpected and, in some cases, theoretically based. Building capacities through physical activity and other health behaviours more

naturally align with physiological public health indicators, while subjective wellbeing outcomes align with restoring capabilities. Yet, it also suggests an opportunity to improve urban NBI design and evaluation with the inclusion of indicators from other pathway domains. This could provide a better understanding of how pathways and pathway domains work independently, as well as synergistically.

It was encouraging to find several instances where health behaviour change theories, as well as mechanisms and behaviour change techniques from the COM-B (Michie *et al.* 2011), TDF (Cane *et al.* 2012), and BCTTv1 (Michie *et al.* 2013) were present in existing NBIs. Our synthesis also indicated that urban greenspace NBIs can positively impact some key physical health and wellbeing outcomes utilised as national and international public health indicators.

However, the fundamental aim of conducting this review was to provide recommendations for future NBI design to improve their potential to positively impact public health. Perhaps unsurprisingly, the first recommendation is that researchers should be explicit about which level(s) of causation they are targeting. Is the focus on the 'black box' (that is, *whether*) and a specific pathway or pathway domain? Or is it on the 'white box(es)' and *how* any effects occur by investigating the mechanisms?

This clarity also facilitates another recommendation: for researchers to use concepts and terminology consistently. We readily acknowledge the complexity of this task given that different disciplines contribute to NBI design, use, and evaluation. However, *within projects*, it is important to be clear in the terms used; this was often not the case in the included studies. As a caveat to these recommendations, we are not suggesting that NBIs become overly mechanistic or biology based. NBIs exist in a complex interplay between person, place, community, and wider societal influences (Barton & Grant 2006, Sallis *et al.* 2006); but NBIs typically operate at the individual level and could benefit from the application of pathways and mechanisms that correspond with biological principles of causal inquiry.

One challenge we experienced in our review was the lack of essential detail in some NBIs, a criticism also common to health behaviour change interventions. Concerns have been raised about the importance of identifying links between theories, pathways, and outcomes to better understand the efficacy of interventions (Prestwich *et al.* 2014). In Prestwich and colleagues' (2014) meta-analysis, only half of 190 exercise and diet interventions utilised at least one specified theory. More concerning, only 10 per cent of those linked intervention techniques to theory. Of the nine studies included in our review, one could be considered best practice because it addressed many of these concerns (Plotnikoff *et al.* 2017). Its strengths included clear use of health behaviour change theory to inform NBI design and detailed intervention descriptions in both a published protocol and the reporting of study findings. A limitation was that it focused only on physical health outcomes. We believe, with minimal burden to participants, there was an opportunity to capture data related to the *nature exposure* pathway and

the *reduction/causation of harm* pathway domains through air quality, allergens, or exposure to different microbiota.

The omission of the *nature exposure* pathway and *reducing or causing harm* pathway domains in the included studies indicates there may be some disconnect between environmental scientists, who focus on these pathways and domains, and researchers in environmental/other social sciences who are more likely to investigate the pathway and domains aligned to their disciplinary interest. Yet to fully understand their public and climate health impact, it is important to evaluate NBIs using complementary data across all pathways and pathway domains. This will ensure that the full health impacts of interventions designed to improve public health are captured, as well as also determine whether NBIs may inadvertently and simultaneously cause harm through exposure.

Across studies, it was also evident that NBIs were proposing pathway domains and mechanisms aligned with environmental social science theory; but interventions were not utilising techniques to invoke those mechanisms. Therefore, another recommendation, albeit a challenging one, is to consider how NBIs can potentially provide evidence to allow different pathways and mechanism to be tested simultaneously. Better NBI design, particularly in urban contexts, has the clear potential to make a positive contribution to public health. These interventions may also foster a change in positive environmental attitudes through the *nature contact/experience* pathway: for example, through mechanisms of nature connectedness or nature-related identity that are linked to pro-environmental behaviours. In that sense, improving urban greenspace NBIs provides an opportunity to improve both public and environmental health simultaneously.

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Appendix. Summary of study urban greenspace nature-based interventions mapped to pathways, pathway domains, mechanisms, and behaviour change techniques.

Sample	*Urban Greenspace*	*Theoretical Description*	*Intervention Framework*	*Pathway Description*	*Pathway Domain*	*Mechanism*	*Target Behaviour*	*BCT*	*Health & Wellbeing Outcomes*
1. Bang, Lee, Kim, Lim, Joh, Park & Song (2017), ***International Journal of Environmental Research and Public Health***									
N = 99 University students Mean age 24.3 47.5% male	University campus near mountain range, tree cover, forest roads and trails	Information–motivation–behavioral skills	**Between subjects design.** **Intervention group**: Group forest walking program 1 × weekly for 6 weeks during lunch Stress management lectures, mental & physical health leaflets including forest therapy effects, correct walking method, self-efficacy for walking, stress & depression management Text message prompt during week Provided activity tracker **Control group:** Daily routine; not provided leaflets, lecture, or activity tracker	Nature contact & experience	**Building capacities** Physical activity/ other health behaviours	Behavioural regulation; Beliefs about capabilities Beliefs about consequences Knowledge Memory, attention & decision- making processes Skills	Physical activity	Biofeedback Self-monitoring of behaviour Instruction on how to perform behaviour Information about health consequences Prompts/cues Reduce negative emotions	Bone density Blood cholesterol Blood Pressure (BP) Body Mass Index (BMI) Body composition + Depression + Health promoting behaviour + Heart rate variability (HRV) + Physical Activity (PA) Total metabolic equivalent of tasks (MET)

Appendix. *Cont.*

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2. Beute & de Kort (2018), ***Apllied Psychology: Health and Well-Being***									
N = 15 students; Mean age 21.6 80% female High level of depression, anxiety and/or stress levels	Images of varied local urban or natural scenes in southern regions of Netherlands	None listed	**Cross-over design** Viewed images on tablet at home 2 × daily (AM, PM) Prompted 6 consecutive days/4 × daily to complete outcome measures Four weeks after the 1st 1-week intervention, repeated participation in other conditions	Nature contact & experience	**Restoring capacities** Psychological	Positive emotion (stress) Memory, attention & decision processes	Reduce negative thinking & rumination	Monitoring of emotional consequences Prompts/cues	Depression Mood + HR + Mental wellbeing; Psychosomatic complaints Perceived stress Rumination + Stress level and worry
3. Caloguiri, Evensen, Weydahl, Andersson, Patil, Ihlebaelk, & Raanaas (2016), ***Work***									
N = 14 Mean age 49 50% female Healthy employees inactive to moderately active	**Outdoor:** forest area and grass-yard **Indoor:** gymnasium with no nature	ART SRT	**Randomised control trial** Baseline measures taken at an information meeting (day 1) 2.5-hour exercise session (day 2 & 3) spaced over 2 weeks *Cycling:* Instruction on workout intensity and	Nature contact & experience	**Restoring capacities** Psychological **Building capacity** Physical activity	Cognitive restoration Positive emotion Behavioural regulation Belief about capabilities Emotion Environmental context & resources Knowledge Skills	Green exercise	Biofeedback Demonstration of the behaviour Instruction on how to perform a behaviour Monitoring of emotional consequences Restructuring the physical environment Self-monitoring of outcome(s) of behaviour	Affect (mood) + Environment perceived restoration potential (EPRS) + Blood pressure (diastolic +) Cortisol (salivary awakening +; serum)

			monitored during activity *Strength training:* 8 exercises Led by experienced instructors Heart rate monitor belt provided						

4. Dolling, Nilsson & Lundell (2017), ***Urban Forestry and Urban Greening***

N = 46 Mean age 48 69% female Individuals with high stress levels	**Outdoor:** Forest environment in northern Sweden **Indoor:** Basement room in a town in Sweden	None listed	**Between-subject design** Randomly assigned to forest or handicraft condition Group participation, 2 hours × twice weekly over 3 months Instructed to engage in a range of activities in the setting Group leader was either a qualified forest ranger or occupational therapist Small meal, activities, group discussion Wearable tracker for sleep monitoring	Nature contact & experience	**Restoring capacities** Psychological	Cognitive restoration Positive emotion (stress) Behavioural regulation Beliefs about capabilities Emotion Knowledge	Relaxation Restoration	Biofeedback Demonstration of the behaviour Instruction on how to perform a behaviour Monitoring of emotional consequences Self-monitoring of outcome(s) of behaviour	Burnout + EPRS Fatigue + Mood + Perceived general health + Physical functioning + Stress + Sleep pattern Social functioning + (Note: + effect in both conditions)

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5. Maund, Irvine, Reeves, Strong, Cromie, Dallimer & Davies (2019), ***International Journal of Environmental Research and Public Health***									
N =16 Most between 30 and 64 50% male Registered with community wellbeing service & diagnosed with anxiety/ depression	Wetlands Trust site in UK nearby to participants	ART	**Pre-post intervention design** 1 × weekly trip to wetland Structured group activities guided by wetland & mental health professionals Each week the activity included some physical activity, introduction to the task, assisted task completion	Nature contact & experience	**Restoring capacities** Psychological	Positive emotion (stress) Behavioural regulation Environmental context & resources Knowledge	Nature engagement	Instruction on how to perform a behaviour Restructuring the physical environment Self-monitoring of outcome(s) of behaviour	Affect (mood) + Generalised anxiety disorder symptoms + Mental wellbeing + Perceived stress +
6. McEwan, Richarson, Sheffield, Ferguson & Brindley (2019), ***International Journal of Environmental Research and Public Health***									
N = 164 (all three timepoints) Mean age 27–30 42–44% male General public but most with mental health conditions	Urban green and built spaces in Sheffield UK	ART SRT 3 Good Things	**Repeated measures time-series design** Randomly allocated to green space or built space condition (70% to greenspace) GPS recorded location initiates prompt to 'enter one good thing	Nature contact & experience	**Restoring capacities** Psychological	Behavioural regulation Cognitive restoration Environmental context & resources Memory, attention & decision processes Positive emotion (stress)	Nature connectedness	Prompt/cues Monitoring of emotional consequences Self-monitoring of outcome(s) of behaviour	Positive affect + Nature engagement Nature identity + Nature relatedness + Quality of life + (Note: + effect in both conditions)

			they noticed' for greenspace condition Built space condition prompted at random during the day Study ran for 7 days Promoted as a social prescription						

7. Muller-Riemenschneider, Petrunoff, Yao, Ng, Sia, Ramiah, Wong, Han, Tai & Uijtdewilligen (2020), ***International Journal of Behavioral Nutrition and Physical Activity***

N = 126 Mean age 51 9% female Recruited through hospital health screening programme	Varied urban parks in/ surrounding Singapore	None listed	**Two-arm, parallel group randomised control trial** **Park prescrip-tion condition:** In-person information session on physical activity & importance of meeting minimum recommended amount Completed a park prescrip-tion sheet with trained counsellor & committed to a goal (frequency, intensity, time, location) Materials to plan weekly	Nature contact & experience	**Building Capacities** Physical activity Other health behaviour	Behavioural regulation Goals Environmental context & resources Knowledge Memory attention & decision processes Social influence	MVPA Other health behaviours	Action planning Behavioural contract Discrepancy between current behaviour & goal Feedback on behaviour Goal setting (behaviour) Information about health consequences Review behaviour goal(s) Prompts/ cues Self-monitoring of behaviour Self-monitoring of outcome(s) of behaviour Social support (unspecified)	Blood pressure BMI Glucose Height Lipoprotein Mental wellbeing MVPA Park use + Physical activity in park + Sedentary time Self-reported physical activity Triglycerides Weight

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			physical activity Information brochures about parks Mid-intervention phone call to assess goal progress/ modification & invitation to group outdoor physical activity sessions Text prompt before sessions **Control group:** Daily routine followed Information brochures about physical activity, brochures provided to intervention condition, invitation to group activity sessions after study completed Accelerometery used to measure activity over 7 days						

8. Payne, Loi & Thorsteinsson (2020), ***Journal of Environmental and Public Health***

N = 200 Mean age 31 78–85% female University students	ART SRT	**Between-subjects design** **Intervention group:** Read vignette about a girl who achieved benefits from engaging with nature Intended to provide information and motivation Instructions to spend 20 min. weekly × 3 weeks between 7 AM and 4 PM in chosen green/ nature setting, encouraged to create a personal reminder (e.g., note or e-alert) Complete alone, take in surrounds, no physical activity during 20 min. **Control group**: Put on a 'waitlist' to be contacted in 3 weeks In 3 weeks, contacted with link to post-study questionnaire	Nature contact & experience	**Restoring capacities** Psychological	Cognitive restoration Positive emotion (stress) Behavioural regulation Beliefs about consequence Goals Knowledge Memory, attention & decision processes Social influence	Increase time spent in nature	Action planning Information about health consequence Goal setting Prompt/cues Social comparison	Burnout Perceived stress + Life satisfaction

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9. Plotnikoff, Wilczynska, Cohen, Smith & Lubans (2017), ***Preventive Medicine***									
N = 84 Mean age 48 70% female At risk or diagnosed with T2 diabetes Obese or overweight = 64%.	Outdoor park setting not described	Social cognitive theory Cognitive behavior theory Health action approach model	**Randomised control trial:** Randomly assigned to waitlist control group or eCoFit intervention group **Intervention phase 1:** Group sessions (30 min. mentoring + 60 minutes outdoor training) Mentoring included strategies to overcome barriers, goal setting, motivational styles, time management, action planning, problem solving Outdoor training included instruction, modelling, learning proper techniques Social support from group	Nature contact & experience	**Building capacities** Physical activity Other health behaviour	Beliefs about capabilities Emotion Goals Knowledge Memory, attention & decision processes Optimism Environmental context & resources Skills Social influences	Improve physical activity and fitness	**Phase 1:** Action planning Biofeedback Body changes Demonstration of behaviour Feedback on behaviour Goal setting (outcome) Instruction on how to perform behaviour Problem solving Restructuring physical environment Self-talk Self-monitoring of behaviour Self-monitoring of outcome(s) of behaviour Social support (unspecified) **Phase 2:** Action planning Demonstration of behaviour Generalisation of target behaviour	Aerobic fitness + BPlood pressure (systolic +) BMI Lower body fitness + Physical activity + Waist circumference + Weight

	Intervention phase 2: eCoFit smartphone app App included outdoor workout circuits, instructions on use (visual), challenges, goal setting, self-monitoring, social media link	Goal setting; Prompts/cues Self-monitoring of behaviour Self-monitoring of outcome(s) of behaviour

ART = attention restoration theory
BCT = behaviour change technique
BMI = body mass index
MVPA = moderate-to-vigorous physical activity
SRT = stress reduction theory
+ indicates that the intervention had a significant, positive impact on that outcome.